VARIABLE FREQUENCY DRIVES

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CHAPTER 1

INTRODUCTION

1.1 WHAT IS MEANT BY VFD?

A variable frequency drive is an electronic controller that adjusts the speed of an electric motor by regulating the power being delivered. Variable-frequency drives provide continuous control, matching motor speed to the specific demands of the work being performed. Variable-frequency drives are an excellent choice for adjustable-speed drive users because they allow operators to fine-tune processes while reducing costs for energy and equipment maintenance.

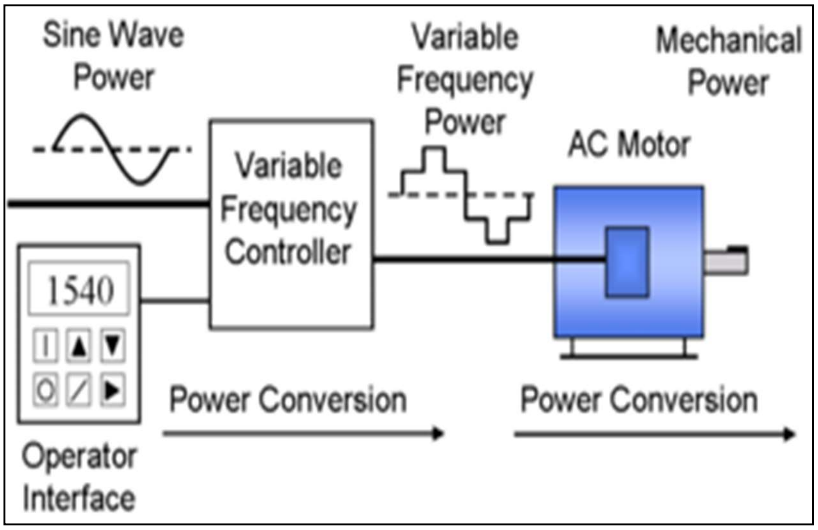


Figure 1- VFD Drive General Outline

1.2 NEED FOR A VARIABLE FREQUENCY DRIVE

Variable speed, depending upon the load requirement, provides significant energy saving. A reduction of 20% in the operating speed of the motor from its rated speed will result in an almost 50% reduction in the input power to the motor.

This is not possible in a system where the motor is directly connected to the supply line.

If a variable voltage variable frequency drive is employed for speed control of a motor, the required level of pressure- head or Flowrate can be maintained at the drum which is different for different load conditions. VFDs allow a motor's speed to be varied electrically instead of by mechanical means. This permits much greater efficiency and flexibility of operation. They can control both the speed of the motor and the torque. Without a VFD, industrial induction motors run at full speed continuously; valves, or other mechanical methods, are employed to control the machine output. Unfortunately, running a motor at maximum speed regardless of the varying demands of production means a great deal of electric power is wasted.

1.3 VFD OPERATION

When an induction motor is first connected to a full voltage supply, it draws several times (up to about 6 times) its rated current. As the load accelerates, the available torque usually drops a little and then rises to a peak while the current remains very high until the motor approaches full speed.

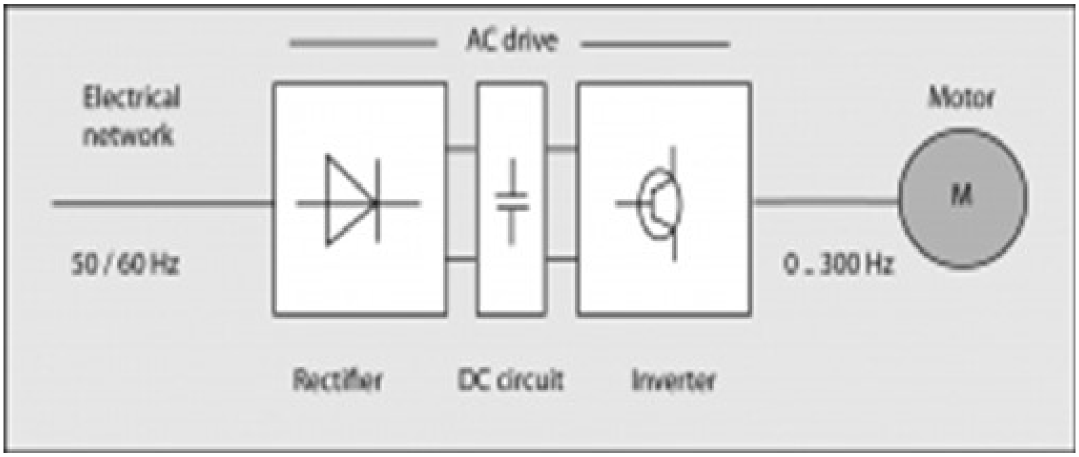


Figure 2- Components of a VFD

By contrast, when a VFD starts a motor, it initially applies a low frequency and voltage to the motor. The starting frequency is typically 2 Hz or less. Thus starting at such a low frequency avoids the high inrush current that occurs when a motor is started by simply applying the utility (mains) voltage by turning on a switch. After the start of the VFD, the applied frequency and voltage are increased at a controlled rate or ramped up to accelerate the load without drawing excessive current. This starting method typically allows a motor to develop 150% of its rated torque while the VFD is drawing less than 50% of its rated current from the mains in the low speed range.

A VFD can be adjusted to produce a steady 150% starting torque from standstill right up to full speed. Note, however, that cooling of the motor is usually not good in the low speed range. Thus running at low speeds even with rated torque for long periods is not possible due to overheating of the motor. If continuous operation with high torque is required in low speeds an external fan is usually needed. The manufacturer of the motor and/or the VFD should specify the cooling requirements for this mode of operation.

CHAPTER 2

COMPONENTS OF A VFD

An ac drive converts the frequency of the network to anything between 0 to 300Hz or even higher, and thus controls the speed of motor proportionally to the frequency.

The technology consists of the following:

Rectifier unit: The ac drive is supplied by the electrical network via a rectifier. The rectifier unit can be uni- or bidirectional. When unidirectional, the ac drive can accelerate and run the motor by taking energy from the network. If bidirectional, the ac drive can also take the mechanical rotation energy from the motor and process and feed it back to the electrical network.

Dc circuit: The dc circuit will store the electrical energy from the rectifier for the inverter to use. In most cases, the energy is stored in high-power capacitors.

Inverter unit: The inverter unit takes the electrical energy from the dc circuit and supplies it to the motor. The inverter uses modulation techniques to create the needed three-phase ac voltage output for the motor. The frequency can be adjusted to match the need of the process.

The higher the frequency of the of the output voltage is, the higher the speed of the motor, and thus, the output of the process.

2.1 COMPONENTS OF VFD IN DETAIL

RECTIFIER

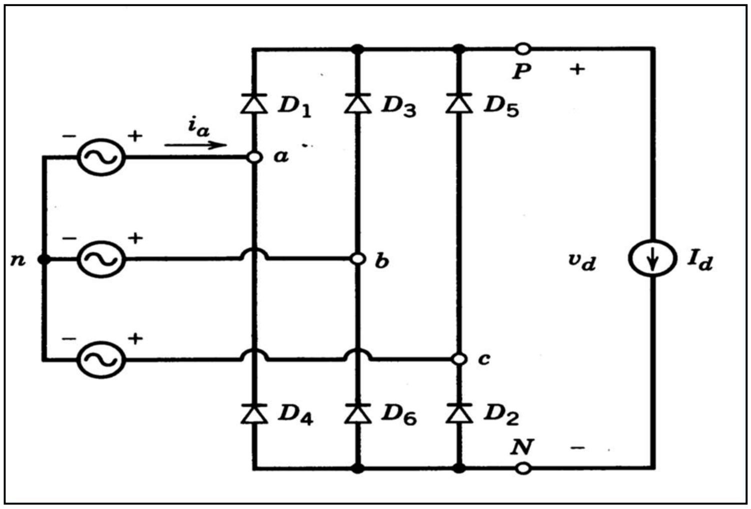


Figure 3- Three phase Power Diode Rectifier

A three-phase bridge rectifier is commonly used in high power applications. Here we use a full wave bridge rectifier which can give six pulse ripples on the output voltage. The diodes are numbered in order of conduction sequences and each one conduct for 120°. The conduction sequence for the diodes is D1-D2, D3-D2, D3-D4,D5-D4,D5-D6 and D1-D6.The pair of diodes which are connected between that pair of supply lines having the highest amount of instantaneous line-to-line voltage will conduct. The line-to-line voltage is √3 times the phase voltage of a three-phase Y-connected source.

The positive group of diodes (D1, D3, D5) conduct when these have the most positive anode. Similarly, negative group of diodes (D2, D4, D6) would conduct if these have the most negative anode. It is seen from the source voltage waveform Vs that from time period wt=300 to 1500, Voltage Va is more positive than the voltages vb,vc.Therefore,diode D_1 connected to line a conducts during this interval.Likewise,from wt=150^0 to 270^0 voltage v_b is more positive as compared to va,vc ;therefore diode D_3 connected to line b conducts during this interval.Similarly,diode D_5 from the positive group conducts from wt=270^0 to 360^0 and so on.

Average value of the output voltage, $V_0=3V_{m/\Pi}$

where V_m is the maximum value of line voltage

INVERTER

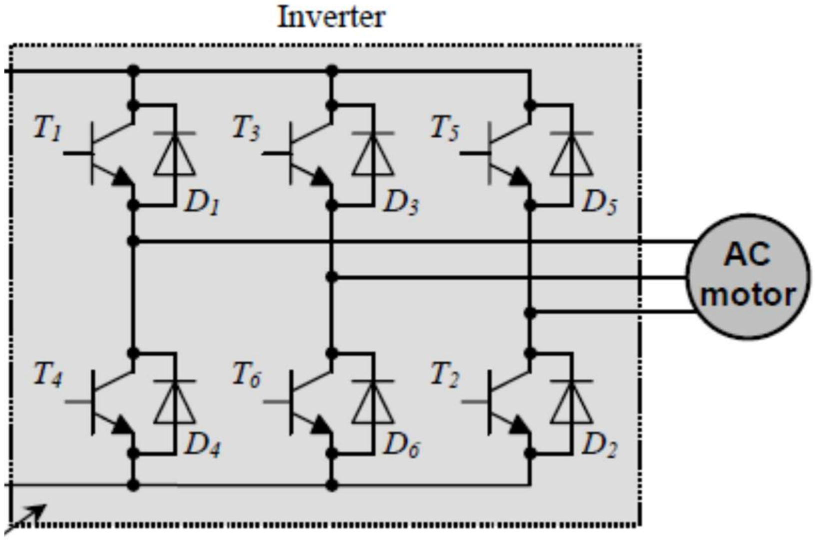


Figure 4- Three Phase Inverter model using Thyristors.

A device that converts DC power into AC power at desired output voltage and frequency is called an Inverter. Phase controlled converters when operated in the inverter mode are called line commutated inverters. But line commutated inverters require at the output terminals an existing AC supply which is used for their commutation. This means that line commutated inverters can't function as isolated AC voltage sources or as variable frequency generators with DC power at the input. Therefore, voltage level, frequency and waveform on the AC side of the line commutated inverters can't be changed. On the other hand, force commutated inverters provide an independent AC output voltage of adjustable voltage and adjustable frequency and have therefore much wider application.

A three-phase inverter is a six-step bridge inverter. It uses a minimum of six thyristors.In inverter terminology, a step is defined as a change in firing from one thyristor to the next thyristor in the proper sequence. For one cycle of 360^0 ,each step would be of 60^0 interval for a six-step inverter. This means that thyristors would be gated at regular intervals of 60^0 in proper sequence so that 3-phase ac voltage is synthesized at the output terminals of a six-step inverter. In the figure the thyristors are numbered in the order in which they are fired.

There are two possible patterns of gating the thyristors.In one pattern, each thyristor conducts for 180^0 and in other, each thyristor conducts for 120^0.But in both these patterns, gating signals are applied and removed at 60^0 intervals of the output voltage waveform.

2.2 THREE-PHASE 180 DEGREE MODE VOLTAGE SOURCE INVERTER

In a three-phase inverter each SCR conducts for 180 of a cycle. Thyristor pair in each arm T_1,T_4,T_3,T_6 and T_6,T_2 are turned on with a time interval of 180.It means that T_1

conducts for 180 and T_4 for the next 180 degree of a cycle. Thyristors in the upper group conducts at an interval of 120.It implies that if T_1 is fired at wt=0,then T_3 must be fired at wt=120 and T_5 at wt=240.Same is true for lower group of thyristors.

2.3 MULTILEVEL INVERTER

The voltage source inverter produces an output voltage or current with levels either 0 or + or- Vdc.They are known as the two-level inverter. To obtain a quality output voltage or current waveform with a minimum amount of ripple content, they require high switching frequency along with various pulse-width modulation (PWM) strategies. In high power and high-voltage applications, these two level inverters,however,have limitations in operating at high frequency mainly due to switching losses and constraints of device ratings.Moreover,the semiconductor switching devices should be used in such a manner to avoid problems associated with their series-parallel combinations that are necessary to obtain capability of handling high voltages and currents.

It may be easier to produce a high-power, high-voltage inverter with the multilevel structure because of the way in which device voltage stress are controlled in the structure. Increasing number of voltage levels in the inverter without requiring higher ratings on individual devices can increase the power rating. As the number of voltage levels increases, the harmonic content of the output voltage waveform decreases significantly.

$$Em=Vdc/(m-1)$$

Where m denotes the number of levels. The term level is referred to as the number of nodes to which the inverter can be accessible. An m-level inverter needs (m-1) capacitors.

2.4 VOLTAGE CONTROL OF THREE-PHASE INVERTERS

PWM (Pulse Width Modulation) design

The AC line supply voltage is brought into the input section. From here, the AC voltage passes into a converter section that uses a diode bridge converter and large DC capacitors to create and maintain a stable, fixed DC bus voltage. The DC voltage passes into the inverter section usually furnished with insulated gate bipolar transistors (IGBTs), which regulate both voltage and frequency to the motor to produce a near sine wave like output.

The term "pulse width modulation" explains how each transition of the alternating voltage output is actually a series of short pulses of varying widths. By varying the width of the pulses in each half cycle, the average power produced has a sine-like output. The number of transitions from positive to negative per second determines the actual frequency to the motor.

Switching speeds of the IGBTs in a PWM drive can range from 2 KHz to 15 KHz. Today's newer PWM designs use power IGBTs, which operate at these higher frequencies. By having more pulses in every half cycle, the motor whine associated with VFD applications is reduced because the motor windings are now oscillating at a frequency beyond the spectrum of human hearing. Also, the current wave shape to the motor is smoothed out as current spikes are removed.

By varying the pulse width, adjustable frequency drives create an output waveform with an average that is a sinusoidal voltage and current waveform for which frequency can be varied. It is this variable output that is used to control motor speed, torque, or position.

PWM is used in modern adjustable frequency drives because it is efficient. The output switches are either on or off, and don't operate in any intermediate states that can increase power dissipation and energy losses.

The advantages of the PWM control are:

(1) PWM control is very simple and require very less hardware. So they are also cost effective.

(2) They can be implemented using DSP or FPGA.

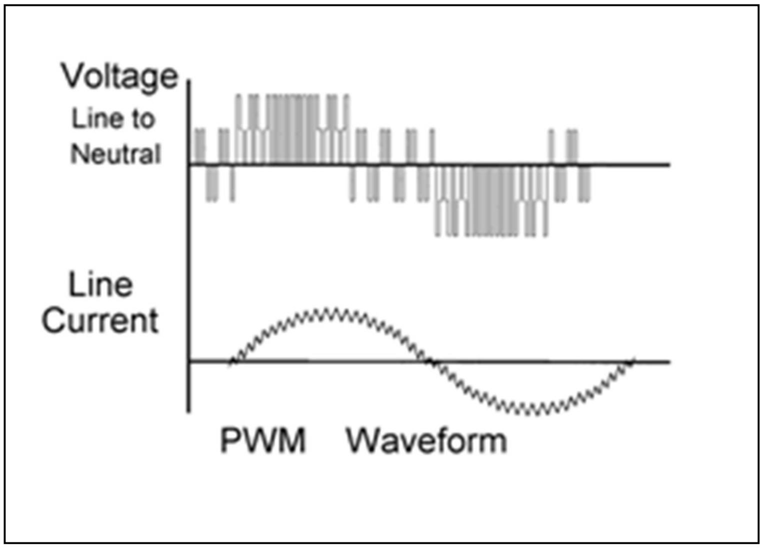


Figure 5- Inverter's Pulse Width Modulation Output shown in above diagram

SINUSOIDAL PULSE WIDTH MODULATION

In this modulation technique a sinusoidal signal is compared with Triangular waveform (Carrier wave) and we will get resultant PWM signal. The width of each pulse is weighted by the amplitude of sine wave at that instant.

RMS Value of output voltage can be controlled by varying the pulse width. The ratio of triangular wave signal frequency (Fc) and frequency of output waveform (Fo) is called frequency modulation ratio i.e. mf = F.

The “Modulation index” (represented by m) is defined by the ratio of the amplitude of the modulated wave(Am) to that of the carrier wave (Ac) and sinusoidal wave signal is called modulation index i.e. (m= Am/Ac). It is the most widely used method of voltage control in Inverters.

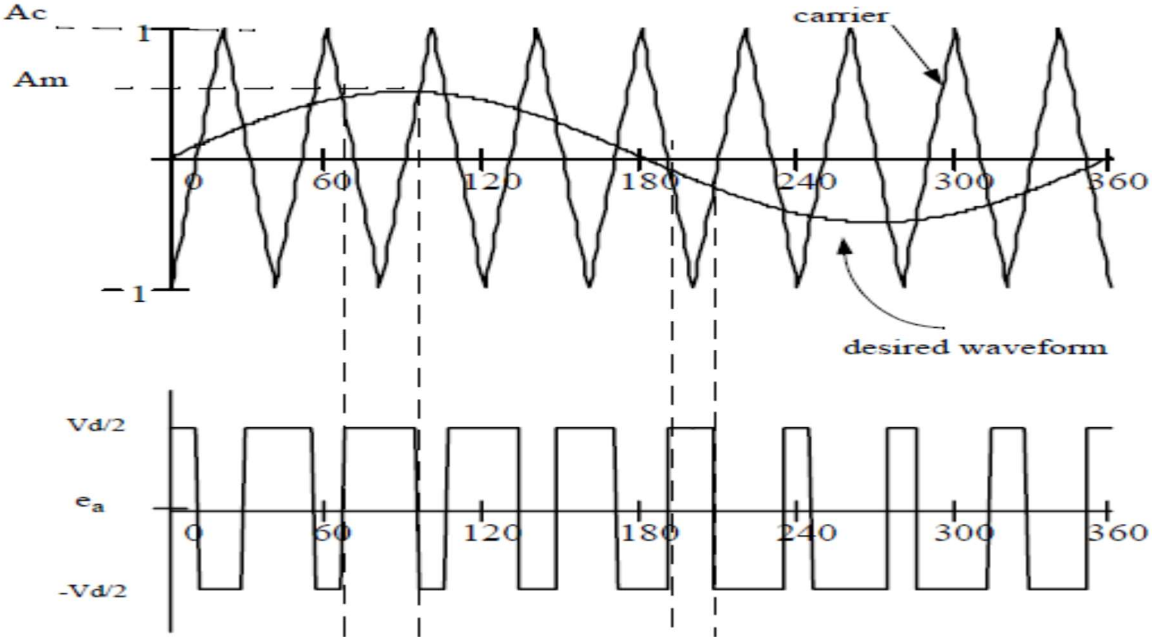


Figure 6- SPWM Pulse Generation

2.5 HARMONIC ELIMINATION IN INVERTER OUTPUT

There are several industrial applications which may allow a harmonic content of 5% of the fundamental component of input voltage when inverters are used. The inverter output voltage may have harmonic content much higher than 5% of its fundamental component. In order to bring this harmonic content to a reasonable limit of 5%, one method is to insert filters between load and inverters. If inverter output voltage contains high frequency harmonics, these can be reduced by a low-pass filter. For the attenuation of low-frequency harmonics, however, the size of the filter components increases. This makes the filter circuit costly, bulky and weighty and in addition, the transient response of the system become sluggish. This shows that lower order harmonics from the inverter output voltage should be reduced by some other means other than filter. Various techniques employed are

1)Harmonic reduction by PWM

2)Harmonic reduction by transformer connection

3)Harmonics reduction by stepped-wave inverters

Harmonic reduction by PWM

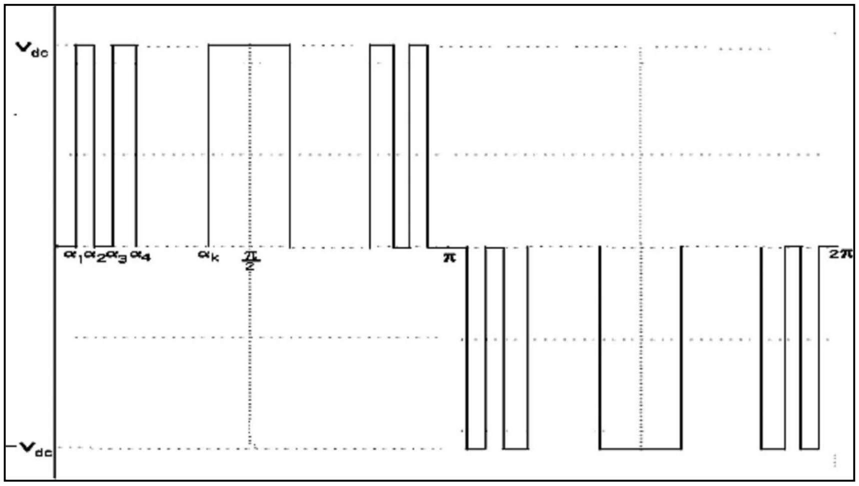


Figure 7- SPWM Modulated Wave

It has already been discussed that when there are several pulses per half cycle, lower order harmonics are eliminated. The voltage waveform is symmetrical about (180^0)and (90^0).

CHAPTER 3

SIMULATION IN MATLAB SIMULINK

3.1 ANALYTICAL MODEL

An Analytical model for simulation of variable voltage variable frequency control (VFD) was made on MATLAB Simulink and the results were recorded. Three phase supply is provided to the circuit by a three-phase source. Three phase supply is rectified by using a full bridge power diode rectifier. The dc voltage from the inverter is filtered using capacitor filter and is fed to an inverter. The inverter used here is a sinusoidal PWM (SPWM) inverter of 180^0 mode. It consists of six IGBT's. The IGBT's are fired in the order they are numbered. First a pulse is given to the IGBT1 and it conducts for 180^0. IGBT2 is fired 120^0 after the triggering of IGBT1. Also, the two switches connected in series in each leg operate in a complementary fashion. Only one of the switches is conducting at any given time to prevent short circuit of the source. Thus, before switch 4 is turned on, the switch 1 must be turned off and vice versa.

RECTIFIER SIMULINK MODEL

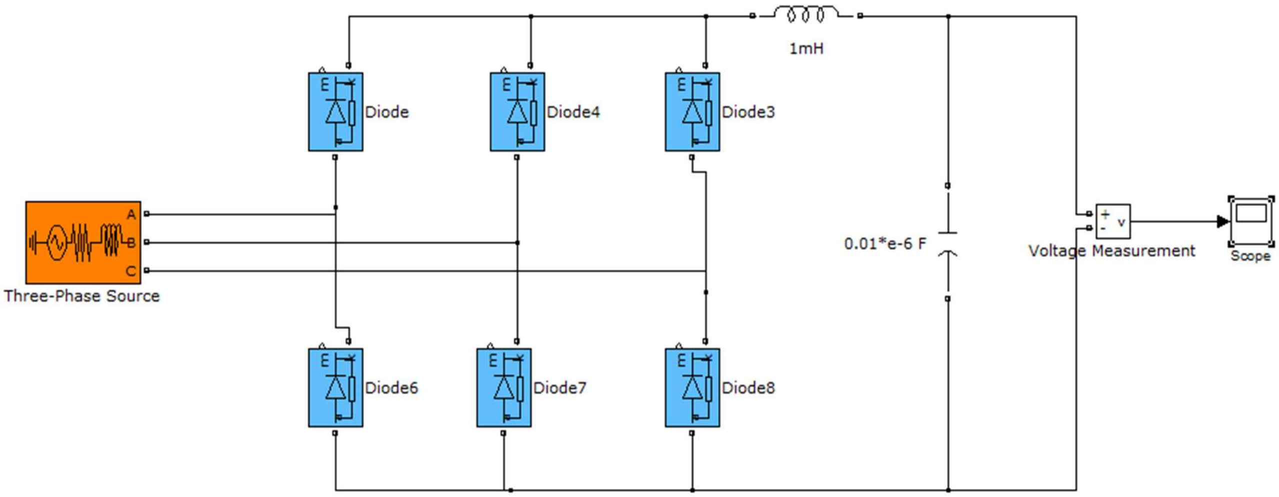


Figure 8- Rectifier Model in Simulink

The rectifier stage consists of a three-phase, full wave diode bridge, though SCRs (Silicon Controlled Rectifiers) are sometimes used in place of diodes. If this stage were isolated from the rest of the power structure, we would see a DC voltage with a 360-Hertz ripple at the DC bus connection when three phase power is applied to the input A filter is required to smooth out the ripple on the DC bus in order to run the IGBT inverter. Therefore, a second or “filter” stage is required. Primarily, this consists of a large Capacitor Filter. Often an inductor may be added. The choke, when used, helps buffer the capacitor bank from the AC line and serves to reduce harmonics.

Output voltage of the rectifier $V_o = 3Vm/\pi$

$$Vm = (\sqrt{2})Vrms$$

OUTPUT OF THE RECTIFIER WITHOUT FILTER.

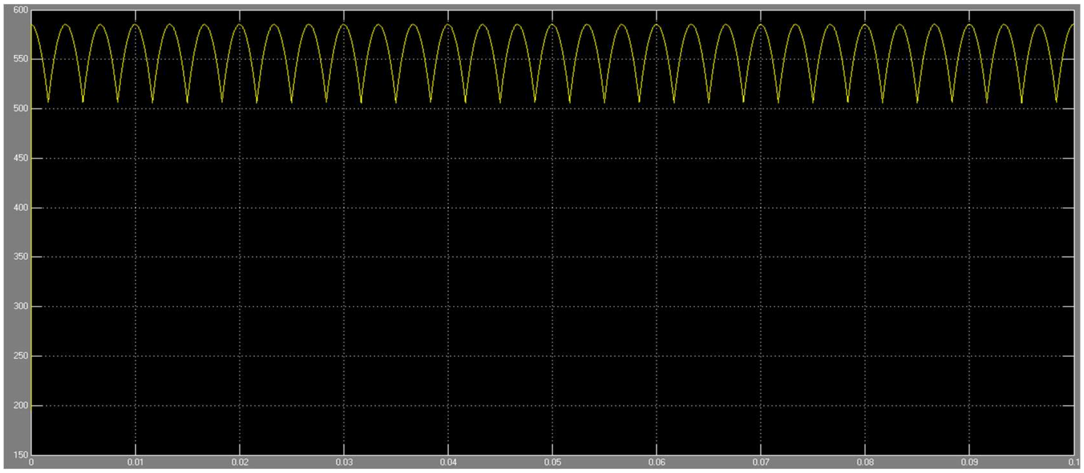


Figure 9- Rectifier Output Unflitered

OUTPUT OF THE RECTIFIER WITH FILTER

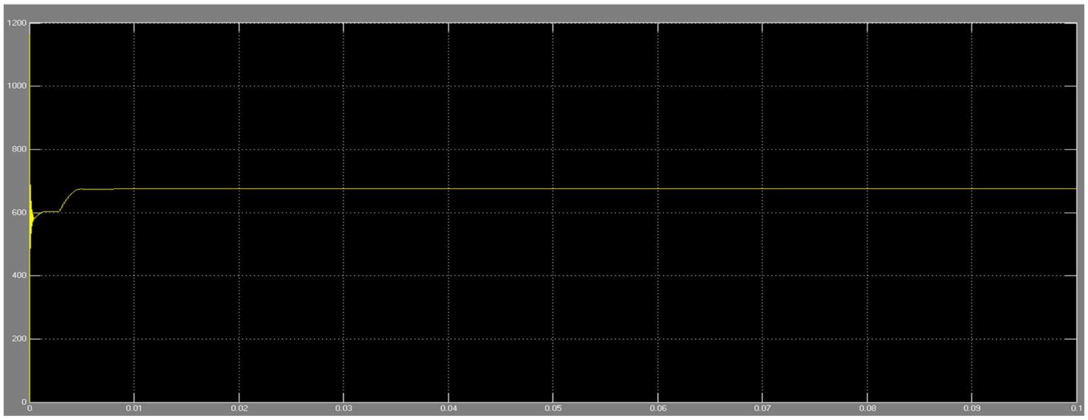


Figure 10- Rectifier Output Filtered

INVERTER SIMULINK MODEL

The three-phase inverter consists of three single - phase legs, each connected to one phase on the output side. The fundamental operation of the three legs is coordinated so that one switch operates at each 60 - degree point of the fundamental output waveform. This creates a line - to- line output waveform that has six steps. The six - step waveform has a zero - voltage step between the positive and negative sections of the square - wave such that the harmonics that are multiples of three are eliminated. Note that switching elements of 3 phase inverters can be operated in the 180-degree conduction and the 120 - degree - conduction.

In order to create a signal which is closer to a true sine wave, a 3 level PWM signal can be generated with high, low, and zero voltage levels. For the resulting 3-level PWM signal to correspond to a sine wave.

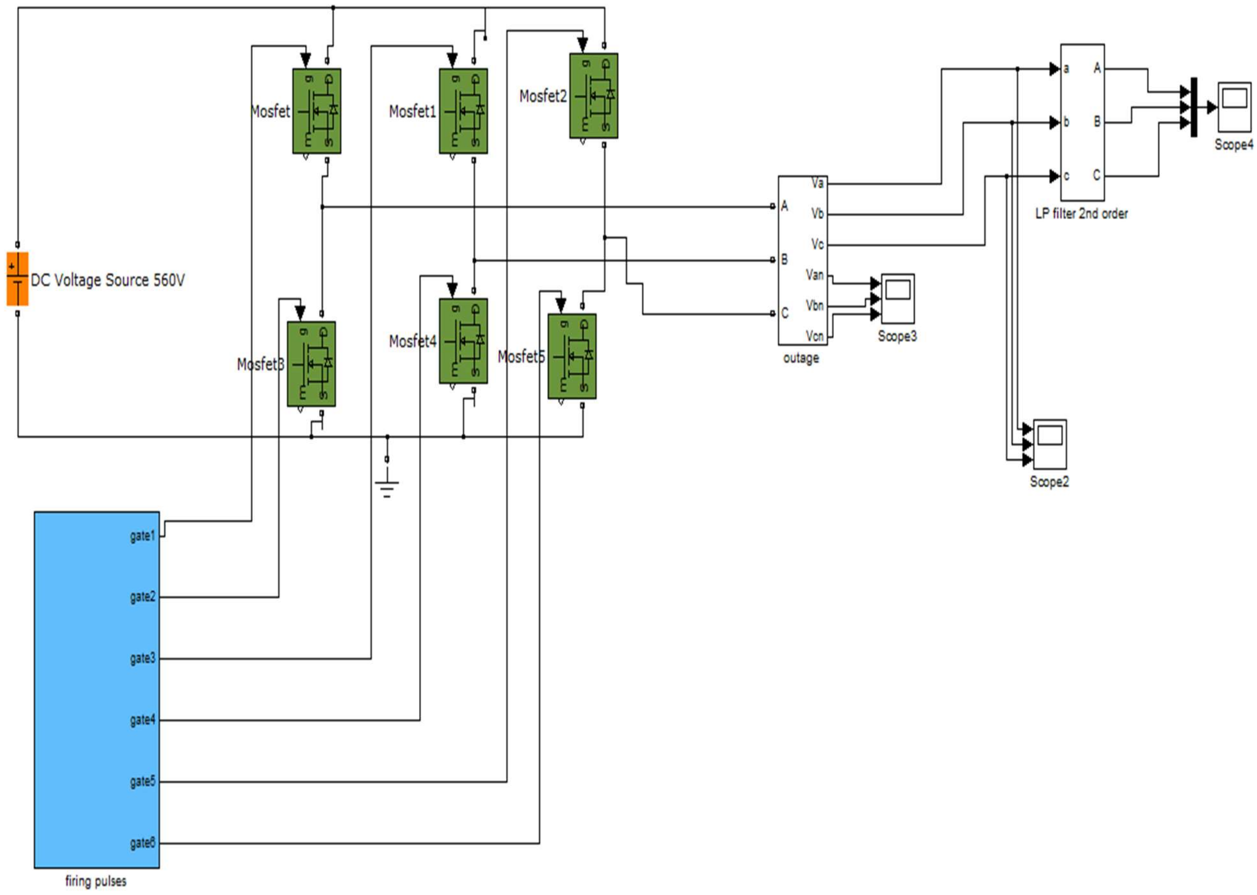


Figure 11- Inverter Model in Simulink

PWM INVERTER

Three-phase reference voltages of variable amplitude and frequency are compared in three separate comparators with a common triangular carrier wave of fixed amplitude and frequency. A triangular-shaped carrier wave is simultaneously used for all three phases. This modulation technique, also known as PWM with natural sampling, is called sinusoidal PWM because the pulse width is a sinusoidal function of the angular position in the reference signal.

INVERTER FIRING PULSE SCHEME

Here three sine waves of phase delay 0^0,120^0,240^0 are generated using the sine function in Simulink. The amplitude of these reference waves are fixed at 5V. The frequency is varied as per the requirement. A triangular wave of magnitude 10V and high frequency is used to generate the firing pulses. In order to vary the frequency of the output voltage of the inverter, the frequency of the reference sine wave is to be varied. The higher order harmonics are eliminated since the carrier frequency is high.

The sine wave with 0-degree phase delay is compared with the triangular wave and its output is fed to the gate of IGBT1.The signal is then inverted and fed to gate of IGBT4.The sine wave with 120-degree phase delay is compared with the carrier and the output pulses are fed to the gate of IGBT3.The inverted pulses are given to the IGBT6. The sine wave with 240-degree phase delay is compared with the carrier and the output pulses are fed to the gate of IGBT5.The inverted pulses are given to the IGBT2.

So, the switch1 conducts for 180 degrees and then it is turned off, after that the other switch which is series in the same leg is turned on and conducts for 180 degrees. In effect the IGBT's numbered 1 to 6 are turned on 60 degrees after the turning on the previous IGBT.

FIRING PULSE GENERATOR MODEL

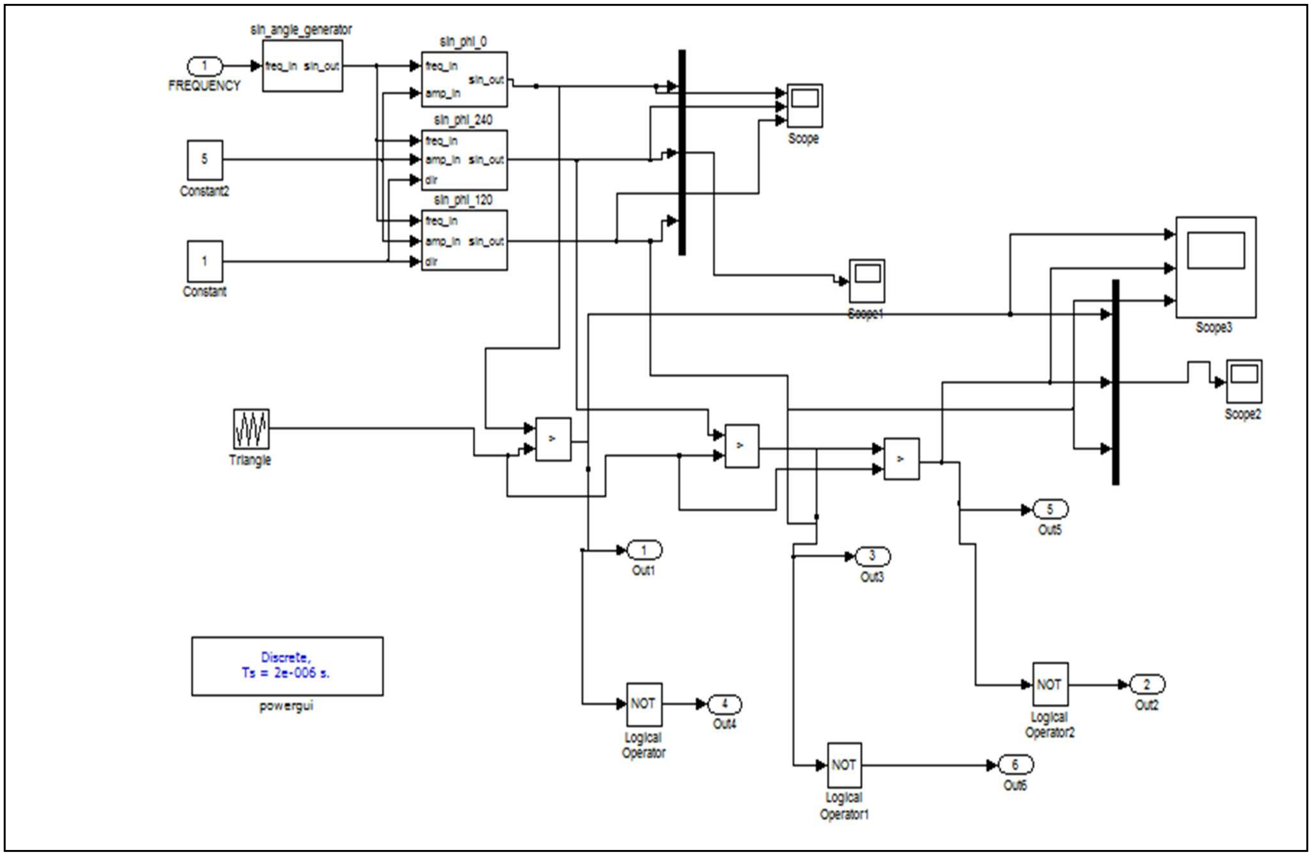


Figure 12- Firing Pulse Generator

CARRIER AND MODULATED WAVE AND THE GENERATED FIRING PULSES

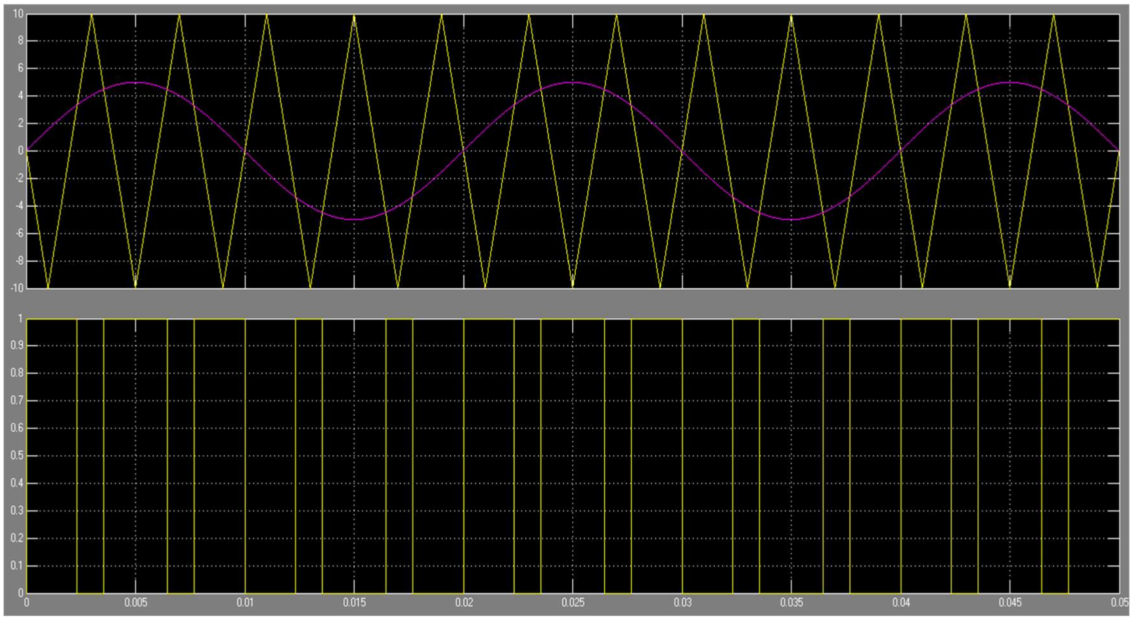


Figure 13- SPWM Output

OUTPUT WAVEFORM OF THE INVERTER

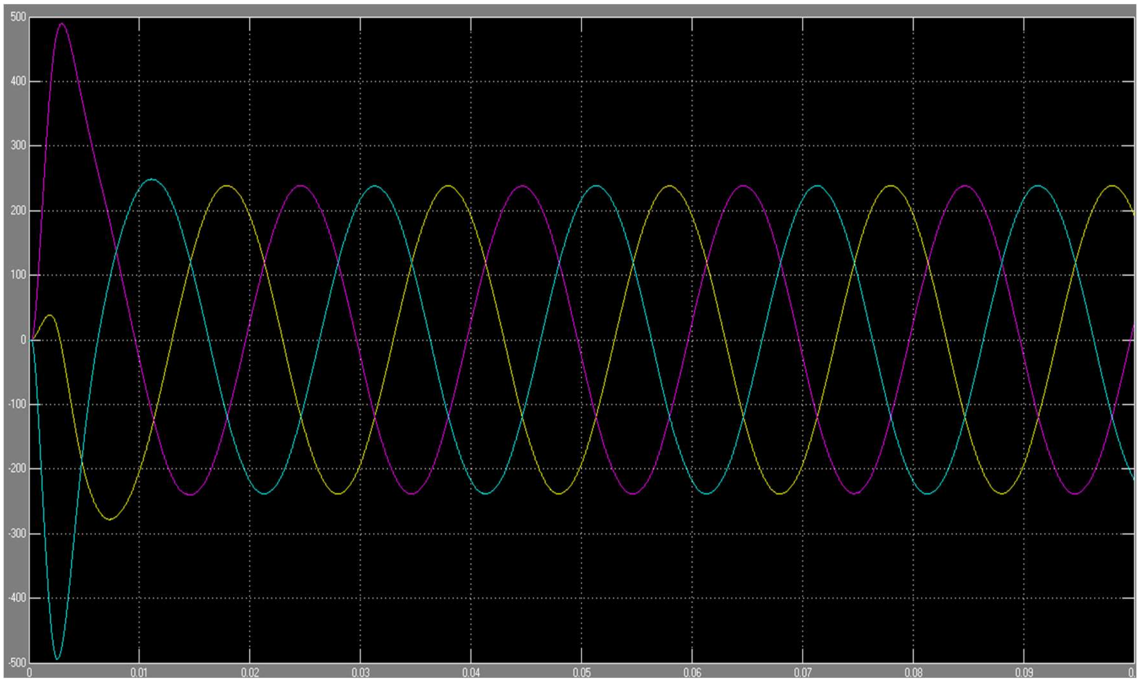


Figure 14- Inverter Output Voltage Waveform

CHAPTER 4

VFD COMMISSIONING PROCEDURES

The Hardware manual of a drive should be referred, for the specific guidelines for commissioning. The below commissioning guidelines are given in respect to the ACS880-37 LV Drive.

4.1 VISUAL INSPECTION

1. Verify ratings of the Variable Frequency Drive and Motor are correct for the proposed installation by reviewing the engineering drawings and specifications.
   Attached the Drive Nameplate, Motor Nameplate and OEM data.

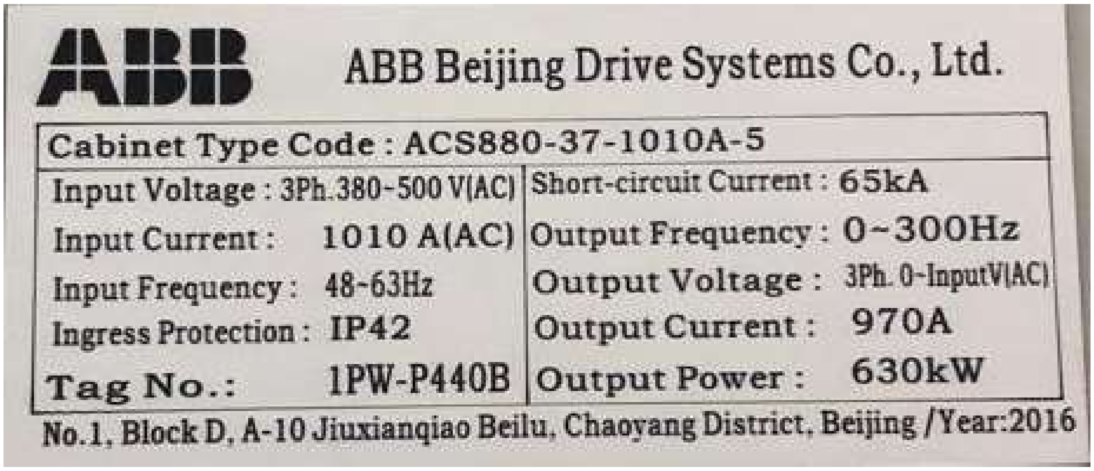


ABB Beijing Drive Systems Co., Ltd.

Cabinet Type Code : ACS880-37-1010A-5

Input Voltage : 3Ph.380-500 V(AC)	Short-circuit Current : 65kA
Input Current : 1010 A(AC)	Output Frequency : 0~300Hz
Input Frequency : 48-63Hz	Output Voltage : 3Ph. 0-InputV(AC)
Ingress Protection : IP42	Output Current : 970A
Tag No.: 1PW-P440B	Output Power : 630kW

No.1, Block D, A-10 Jiuxianqiao Beilu, Chaoyang District, Beijing /Year:2016

Figure 15- VFD Nameplate

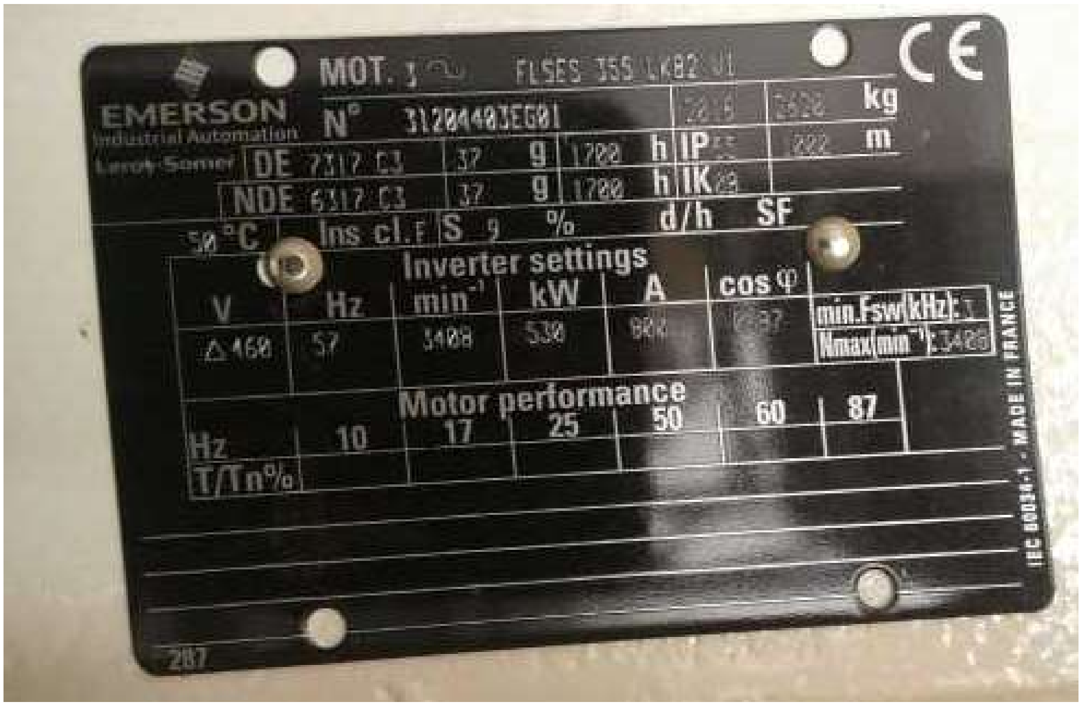


Figure 16- Motor Name Plate

2. Check nameplate voltage and current rating for breakers, contactors, and fuses.

3. Compare overload devices (external and internal to VFD) with motor full load current for proper sizing.

4. Verify grounding is correctly installed and connected to the main grounding system.

5. Inspect for physical damage, missing or improper parts. Check compartments and equipment for cleanliness.

6. Verify power and motor cable sizing is correct and are properly terminated.

7. Isolation transformer (if supplied) is properly rated.

8. Verify jumpers, overloads devices and parameter settings of VFD are properly set or programmed according to the manufacturer's instructions.

9. Verify speed, voltage, current transducers etc. are properly installed and wired.

10. If applicable, check that the rating of output inductors is correct and meet manufacturer recommended ratings for the motor cable length.
11. Check that parameter settings schedule is available and has been reviewed by engineering.

12. Vendor manuals are available.

4.2 MECHANICAL INSPECTION

1. Motor is properly mounted, and motor and load couplings are properly installed and aligned.

2. Motor shaft is free to rotate.

3. Contactors, switching devises, and isolation devices work properly.

4.3 ELECTRICAL TESTS

1. Verify insulation resistance (megger) of power cables, from the VFD to the motor. Note: The power cables must be disconnected from the VFD. Do not (megger) VFD. Record (megger) readings.

2. All instrument / Sensor cables are properly terminated in the motor side.

3. The Estops in the Field are Fixed properly with Normally Closed contacts.

4. The PTC sensor resistance in the ambient range and the PTC sensor cables are terminated up to the drive properly.
5. Motor space heater supply is verified up to the terminal and the heater is working properly.

6. The supply for the motor bearing heater and the bearing lubricator is verified up to the field.

7. Verify supply/isolation transformer is properly connected, tightened, cleaned, if applicable.

8. Verify ratio of current and voltage transformers and that voltage transformers are properly fused.

9. Verify transducers (if applicable) are properly calibrated.

10. Checked operation and calibration of thermal overloads by current injection. Functionally test VFD internal overload protection, if applicable.

11. Check operation of temperature measuring devices (e.g. thermostat) integral to the motor, if applicable.

4.4 VARIABLE FREQUENCY DRIVE AND MOTOR NO-LOAD TESTS

1. Verify motor is uncoupled and safely isolated against accidental contact by personnel.
2. Ensure the Pre-Commissioning Checklist is properly checked and satisfied.

3. Checkout the Schematic drawing for the VFD and Control circuit and properly check all the circuits and verify it. Attached a sample schematic.

4. All the Estop circuits are continuous up to the drive- Estop monitoring relay

5. check the PTC Sensor resistance upto the drive relay point. Ensure the PTC sensor is installed properly.

6. Ensure the control wiring is properly fixed and all the cables are in proper place.

7. Ensure the Control cables for Start, Stop, Speed, Current and Feedback from DCS are verified from the Drive up to the DCS end.

8. The resistance of the PTC circuit can be varied with a variable resistance pot and the PTC function check can be carried out.

9. Open all the panel doors of the drive for visual inspection, rack out the VFDs from the Panels to the cabinet is clean from any dust or debris.

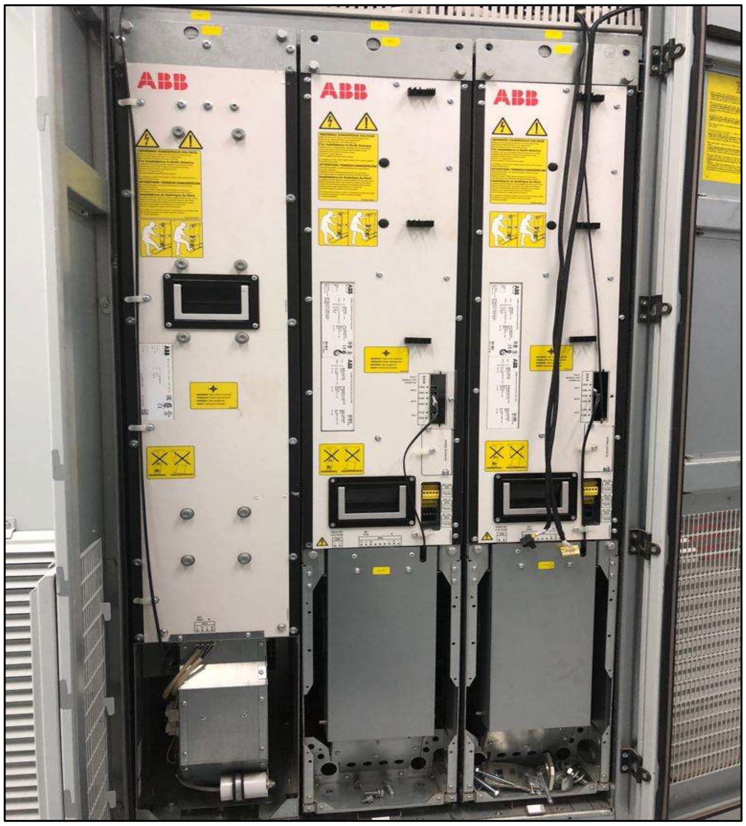


Figure 17- Visual Inspection and Cleaning

6. Clean all the dust and debris from the panels with a vacuum cleaner and wipe the extra dust with clean cloth (do not use air blower, only use vacuum cleaner).
7. There should not be any metal powder or dust leftover due to drilling/Grinding inside the panels.
8. Ensure there are no loose materials in all the drive panels.
9. Visually check for all the components are installed in correct place.

10. Check the torque tightness of the following connections.
    a. Input supply cable from the LV distribution board to VFD.
    b. Connection of the Converter and Inverter unit to the busbar.
    c. Cables from the drive output to the motor.

(All the joints and connections should be torque tightened to 70 Nm).

6. Visually check for all the components are installed in correct place.

7. Check the torque tightness of the following connections.
    a. Input supply cable from the LV distribution board to VFD.
    b. Connection of the Converter and Inverter unit to the busbar.
    c. Cables from the drive output to the motor.

(All the joints and connections should be torque tightened to 70 Nm).

8. Ensure that the fiber optic cables are connected correctly and properly. Any damaged fiber optic cable should be replaced with good one.

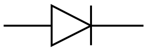
Checklist for the major no-power checks in the VFD

- Safety — with the system at less than 10 Vdc
- An input check — as a diode check
- A dc bus check — as a visual check
- An output check — as a diode check
- A review of checks

Safety when working with VFDs

Life-threatening voltage and current are present in the VFD even after the incoming supply is removed. Before testing, follow the lockout/tagout procedures for the system at hand. After this is completed, follow arc-flash procedures for the given system and follow local codes.

Locate the +(positive) and –(negative) dc bus terminals on the drive.

The multimeter should have at least a 1,000-V CAT III rating and the ability to make diode checks. 

Set the multimeter to V(dc). Connect the +(Red) and -(Black) leads from the meter to the dc bus terminals on the VFD. If the value is above 10 Vdc but reducing, wait until the excess dc bus voltage is below 10 Vdc. This time varies depending on the drive capacity. If voltage does not fall below 10 Vdc, ensure input power to the drive is removed or contact the VFD manufacturer or installer.

1. Check the continuity between the input supply cables to ground and between the phases.
   L1-G, L2-G, L3-G: Should be Open circuit.
   L1-L2, L2-L3, L3-L1: Should be Open circuit.

2. Check for the continuity of all the AC and DC Fuses in the drive.

3. Test the resistance of the balancing resistance in the drive with fluke meter. (DC +ve and -ve)

4. Check the busbar continuity between phases and between Busbar to ground.
   L1-L2, L2-L3, L3-L1: Should be Open circuit
   L1-G, L2-G, L3-G: Should be Open circuit

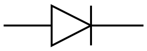
5. Check for the Motor Winding Resistance (multimeter in inductance mode) from the output cables of the Inverter. It should give some value of Inductance comparable with Motor FAT results.

CHECKS AT THE INPUT SIDE OF VFD (RECTIFIER SIDE).

For simple understanding of the concept, we assume the input or rectifier section is comprised of input diodes that convert an incoming three-phase ac sine wave into a rectified dc supply.

There are at least two diodes for each phase. They are positioned in opposite conducting orientation to allow full-wave rectification. To check the input section, we need to perform simple diode checks. These checks include testing the forward and reverse bias direction of both diodes in each phase. This process uses the input terminals R/L1, S/L2, T/L3 on the drive and the dc bus terminals.

If you are unsure about where the input terminals are, refer to the VFD's manual.

With a multimeter set to diode check. 

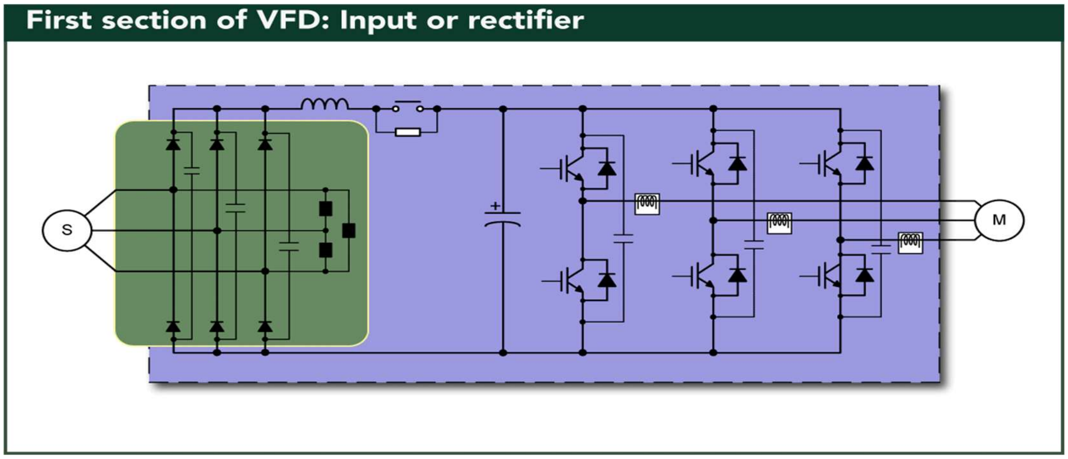


Figure 18- The first section of a VFD is the input rectifier section

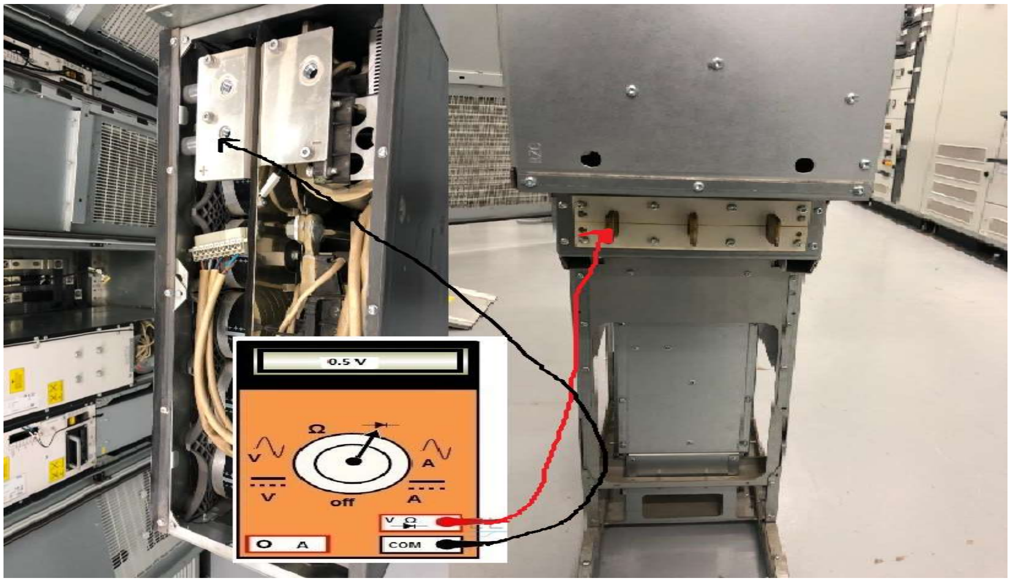


Figure 19- IGBT healthiness check at the input side of the VFD

Put the +(Red) lead on the input terminal (R/L1) and the –(Black) lead on the (+) DC bus terminal. This isolates the positive R/L1 phased diode. A good diode should read around 0.5 Vdc in the forward-bias direction. Repeat this process for the S/L2 and T/L3 terminals while leaving the –(Black) lead on the (+) dc bus terminal.

CHECKS ON THE INPUT OF A VARIABLE FREQUENCY DRIVE			
STEP	**(+) MULTIMETER LEAD**	**(-) MULTIMETER LEAD**	**MULTIMETER READING (DIODE CHECK)**
1	R/L1, S/L2, T/L3	(+) Terminal	0.5 Vdc (approximately)
2	(+) Terminal	R/L1, S/L2, T/L3	OL
3	(-) Terminal	R/L1, S/L2, T/L3	0.5 Vdc (approximately)
4	R/L1, S/L2, T/L3	(-) Terminal	OL

Note: When making this measurement, look for consistency across all three input terminals. The measurement of 0.5 Vdc is only an approximation and can change depending on the VFD and model size. If at any time the meter reads 0 V, then that diode is shorted.

The next step is to check the reverse bias direction of the diodes. Move the –(Black) multimeter lead to the R/L1 terminal and move the +(Red) multimeter lead to the (+) dc bus terminal. Then check the remaining two inputs by moving the –(Black) multimeter lead to the S/L2 and T/L3 terminals. The multimeter should eventually display (OL) after charging the drive's filter capacitors. OL occurs when the power supply in the meter is unable to force current through the diode in the set direction.

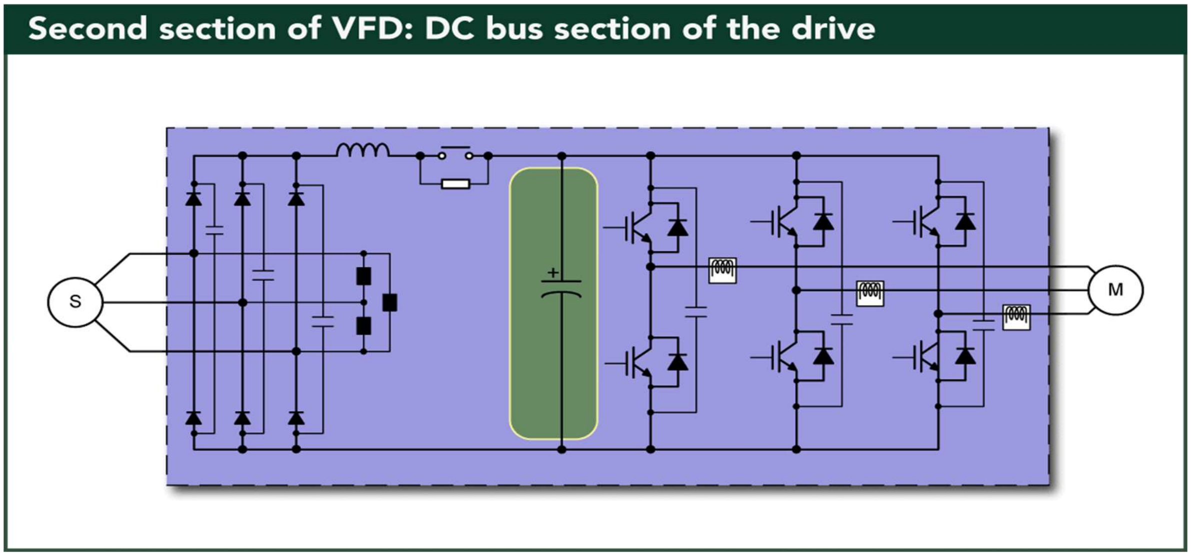
We are now done with the upper diodes and need to check both directions of the remaining diodes on the rectifier. We start by placing the +(Red) multimeter lead on the (-) bus terminal and the –(Black) multimeter lead on the R/L1 terminal. This again should read around 0.5 Vdc. From there, move the –(Black) multimeter lead to the remaining S/L2 and T/L3 terminals while looking for consistency between the three measurements. Some engineers consider a variance of more than 0.05 Vdc between them to be a bad sign, as this could mean that one or more diodes need replacement.

Finally, move the -(Black) multimeter lead to the (-) dc bus terminal and the +(Red) lead to the R/L1 input terminal, then check the S/L2 and T/L3 input terminals, again making sure that the meter reads OL after a short time charging the filter capacitors. When charging the filter capacitors, the time can vary and increases with drive size.

We have now checked all the diodes in both bias directions. If at any time the meter reads 0 V, then that diode is shorted.

DC BUS CHECK ON THE VFDs

After the diodes rectify the incoming ac wave into dc, the dc bus or dc capacitors store the voltage and have a smoothing effect on the dc bus voltage ripple.



Second section of VFD: DC bus section of the drive

Figure 20- The second section of a VFD is the DC bus section.

visual inspection for any signs of physical damage or electrolytic fluid leaking from the capacitor is enough. Sometimes it is even possible to smell if the capacitor is not good anymore and the smell will most likely be a strong scent.

If the unit in question has a lot of hours on it and maintenance personnel are already replacing other components, it is not a bad idea to go ahead and replace the dc bus capacitors.

As an easy No Volt check on the Capacitor you can use the multimeter in diode mode to charge and discharge the capacitor (up to the multimeter potential (usually 9V)).

Place the +(Red) lead of the multimeter to the (+) dc bus terminal and the -(black) lead of the multimeter (-) dc bus terminal of the drive.

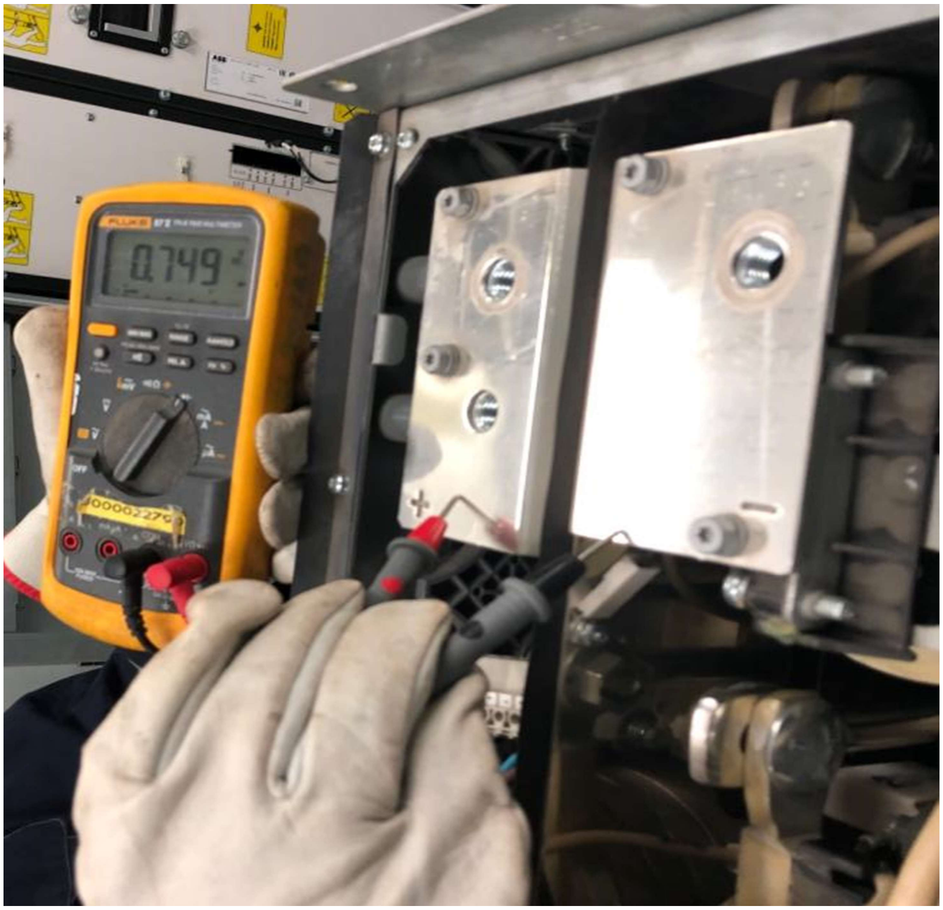


Figure 21- Capacitor Group Healthiness Check

The capacitor in the drive will slowly charge up to 9 V. (from the multimeter). If we reverse the multimeter leads on the dc bus of the drive the capacitor will begin to discharge. This way we can ensure the capacitor is charging and discharging.

But, If the drive is kept idle and not powered up for one year, then we need to perform a **capacitor reforming** before energizing the drive.

VFD OUTPUT CHECK (AT THE INVERTER SIDE)

The third and final section is the output or inverter section. This usually consists of insulated gate bipolar transistors (IGBTs). The IGBTs take stored dc from the bus capacitors and work together to form a simulated ac output wave to the motor. The VFD uses pulse-width modulation (PWM) to control the voltage and frequency applied to the motor. The IGBT includes an emitter, collector, gate and free-wheeling diode. The VFD modulates the pulses applied to the motor by varying how long it applies a voltage between the gate-emitter junctions of the IGBT. This is called gating and it happens thousands of times per second.

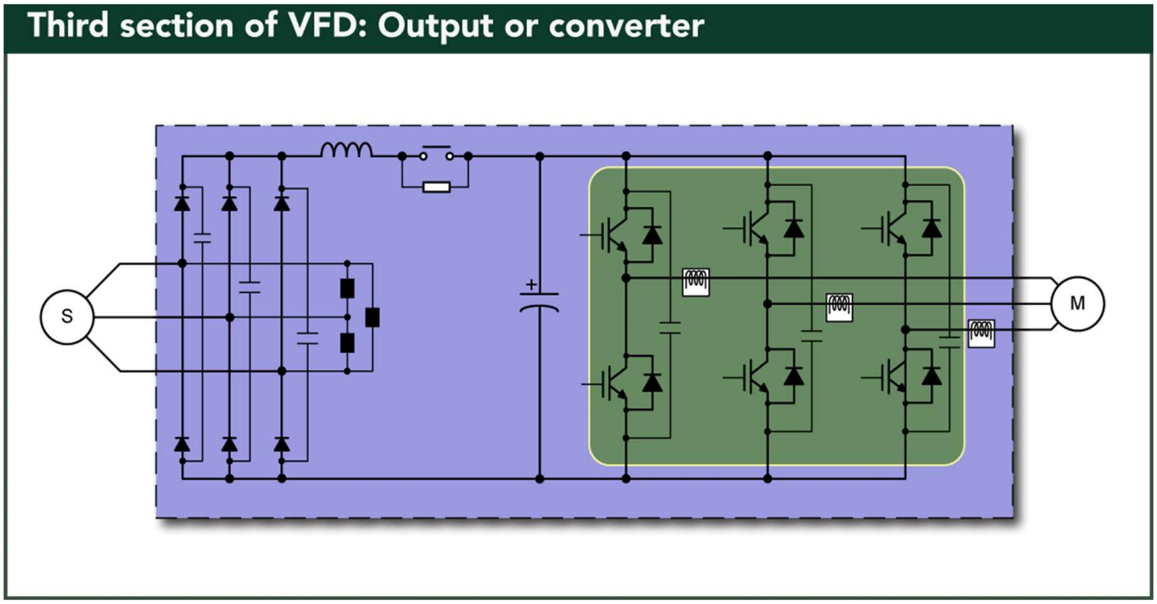


Figure 22-The final VFD section is the output or converter.

CHECKS ON THE OUTPUT OF A VARIABLE FREQUENCY DRIVE			
Step	**(+) Multimeter lead**	**(-) Multimeter lead**	**Multimeter reading (diode check)**
1	U/T1, V/T2, W/T3	(+) Terminal	0.5 Vdc (approximately)
2	(+) Terminal	U/T1, V/T2, W/T3	OL
3	(-) Terminal	U/T1, V/T2, W/T3	0.5 Vdc (approximately)
4	U/T1, V/T2, W/T3	(-) Terminal	OL

The gating signals themselves cannot be checked without power and are usually checked once power is applied, and the drive is running with no load — in other words, with no motor. That check involves using an oscilloscope to ensure the IGBTs are gating properly.

The free-wheeling diode completes the output circuit and handles any regeneration from the motor going back into the drive. This regenerated energy is then introduced back into the dc bus capacitors.

Our last check is basically another set of diode checks. Fortunately, in most cases the IGBT fails because the free-wheeling diode has shorted. How do we check this? We check it the same way we did the VFD’s input. More specifically, check the free-wheeling diodes just as the rectifier’s diodes were checked … but this time, use the U/T1, V/T2, and W/T3 terminals instead of the R/L1, S/L2, and T/L3 terminals. If the measurements show a good diode, you’re done. If the measurements show a short circuit (less than 0.5 Vdc in both directions) then you have a shorted IGBT.

Review of Checks for Out of Range Values

Note that these checks cover the major components of the drive's main circuit. If you have readings that are not in this range, then it is likely that you must remove the drive and either rebuild or replace it.

4.5 ENERGIZING AND COMMISSIONING OF THE DRIVE

1. Check the protection setting in the Input Feeder and Energize the Input voltage.

2. Energize the control voltage of the VFD panel.

3. Check if there are any alarms in the display, if there is any alarm, Reset it. For example. Safe Torque OFF alarm "Fault 5091" – corresponds to Emergency stop button pressed in the field or panel. While the control voltage is ON for the first time this Fault must be reset.

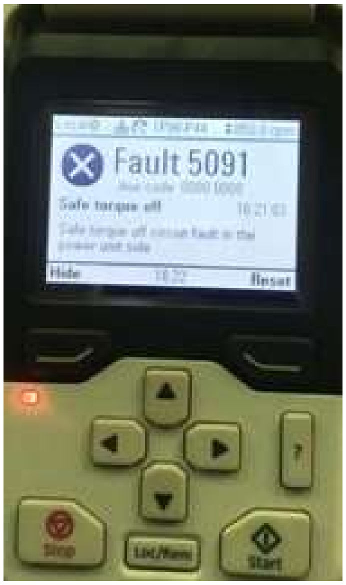


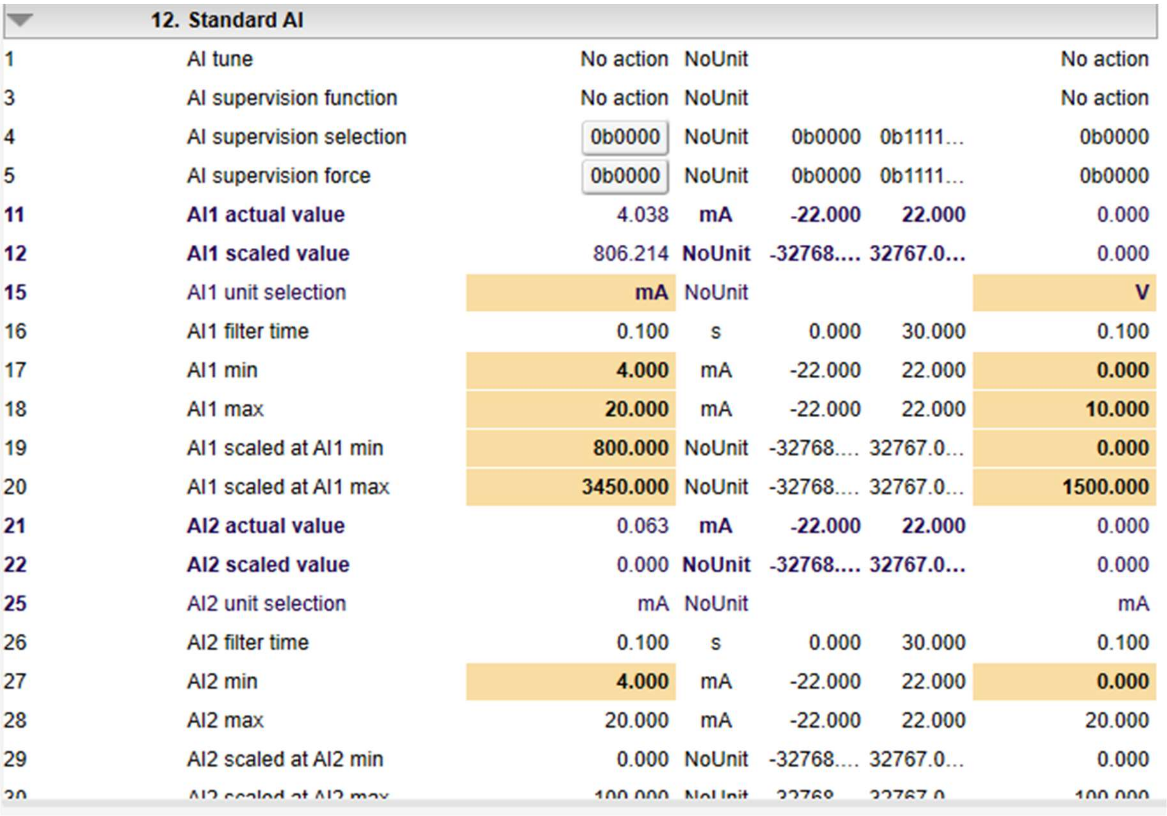
Figure 23- Fault 5091

4. Cabinet heater should be ON, while the drive is OFF, turn off the heater when the drive is ON. (Condition for Cabinet Heater Supply - Cabinet Heater MCB ON + Control Supply ON + All Panel Doors Closed).

5. Verify the parameters in the drive with drive composer software.

6. Ensure the settings related to the motor name plate and OEM data are verified and properly kept in the drive. Check the motor name plate data and program the motor parameters into the VFD. Check for motor direction and ensure the direction is correct.

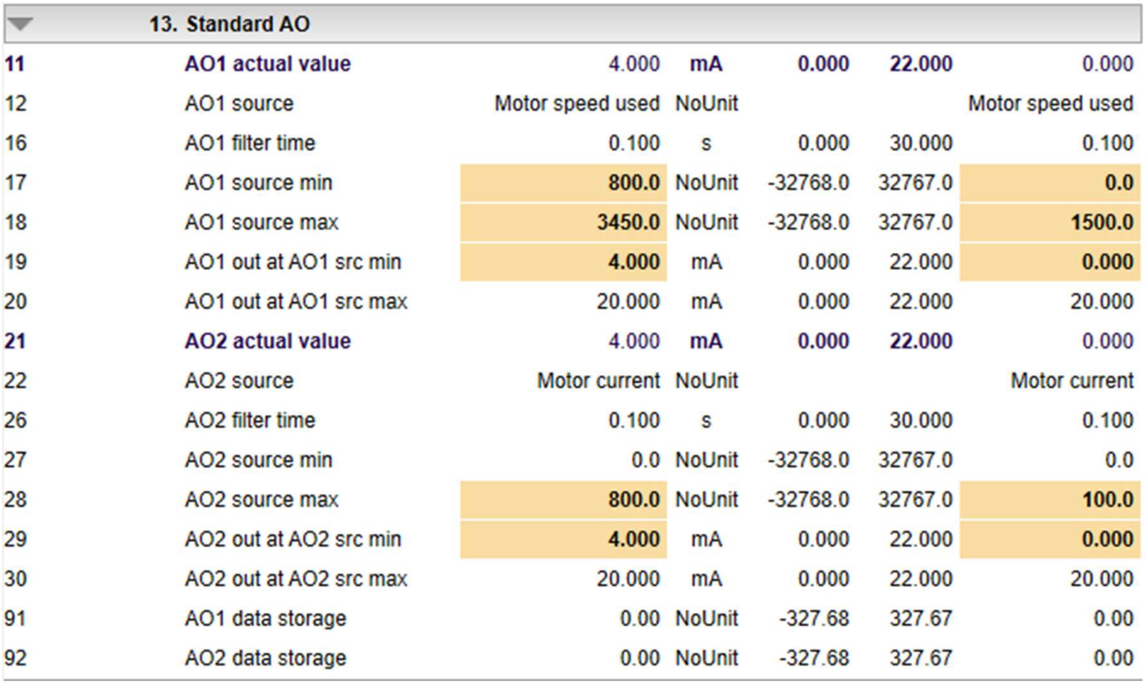
7. Ensure the VFD settings for the following sections.
   12. Standard AI
   13. Standard AO
   30. Limits
   99.Motor Data



12. Standard AI

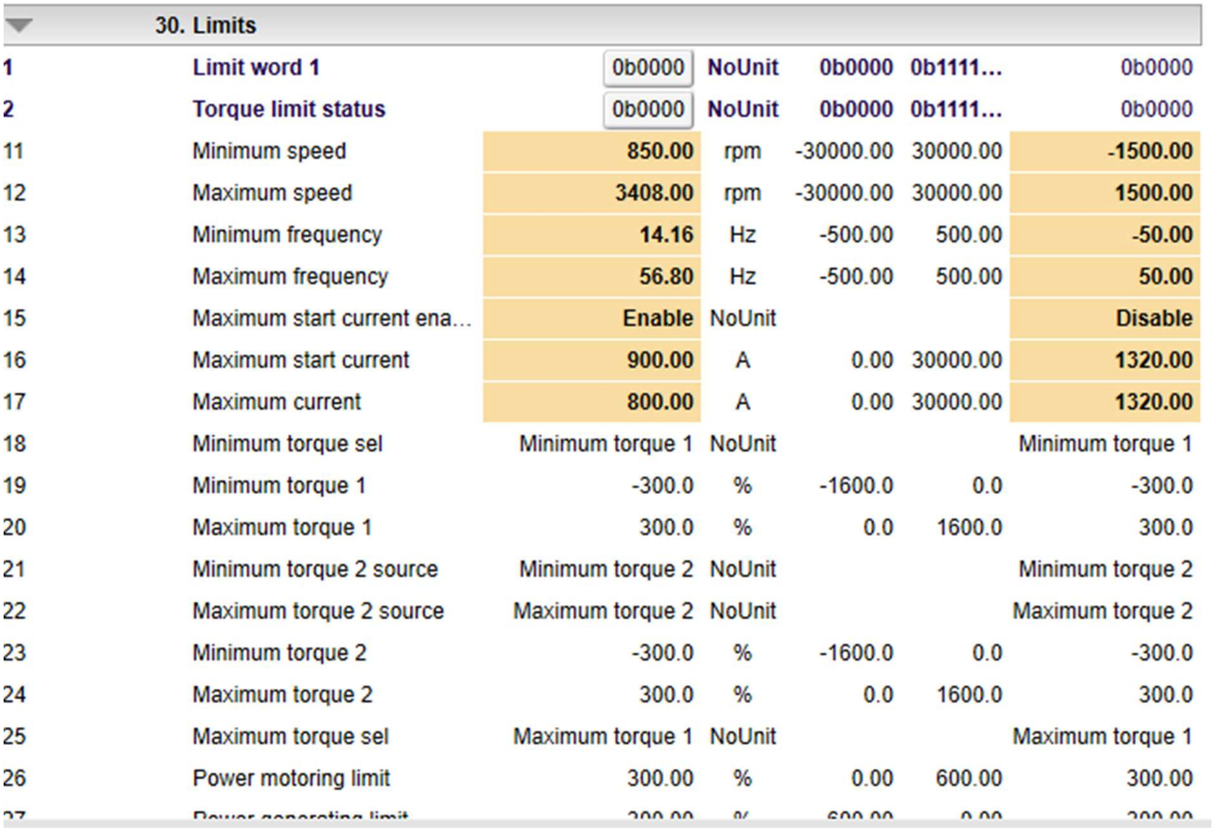
1	AI tune	No action	NoUnit			No action
3	AI supervision function	No action	NoUnit			No action
4	AI supervision selection	0b0000	NoUnit	0b0000	0b1111...	0b0000
5	AI supervision force	0b0000	NoUnit	0b0000	0b1111...	0b0000
11	**AI1 actual value**	4.038	**mA**	**-22.000**	**22.000**	0.000
12	**AI1 scaled value**	806.214	**NoUnit**	**-32768....**	**32767.0...**	0.000
15	AI1 unit selection	**mA**	NoUnit			**V**
16	AI1 filter time	0.100	s	0.000	30.000	0.100
17	AI1 min	**4.000**	mA	-22.000	22.000	**0.000**
18	AI1 max	**20.000**	mA	-22.000	22.000	**10.000**
19	AI1 scaled at AI1 min	**800.000**	NoUnit	-32768....	32767.0...	**0.000**
20	AI1 scaled at AI1 max	**3450.000**	NoUnit	-32768....	32767.0...	**1500.000**
21	**AI2 actual value**	0.063	**mA**	**-22.000**	**22.000**	0.000
22	**AI2 scaled value**	0.000	**NoUnit**	**-32768....**	**32767.0...**	0.000
25	AI2 unit selection	mA	NoUnit			mA
26	AI2 filter time	0.100	s	0.000	30.000	0.100
27	AI2 min	**4.000**	mA	-22.000	22.000	**0.000**
28	AI2 max	20.000	mA	-22.000	22.000	20.000
29	AI2 scaled at AI2 min	0.000	NoUnit	-32768....	32767.0...	0.000
30	AI2 scaled at AI2 max	100.000	NoUnit	32768	32767.0	100.000

Figure 24- Standard AI Parameters



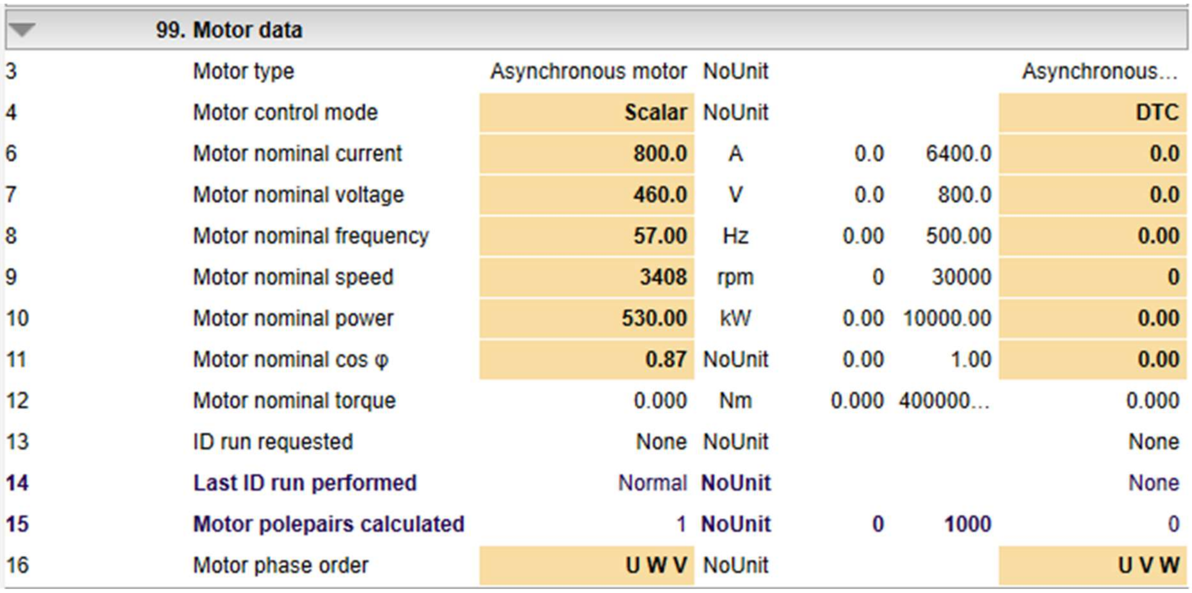
13. Standard AO						
11	**AO1 actual value**	4.000	**mA**	**0.000**	**22.000**	0.000
12	AO1 source	Motor speed used	NoUnit			Motor speed used
16	AO1 filter time	0.100	s	0.000	30.000	0.100
17	AO1 source min	**800.0**	NoUnit	-32768.0	32767.0	**0.0**
18	AO1 source max	**3450.0**	NoUnit	-32768.0	32767.0	**1500.0**
19	AO1 out at AO1 src min	**4.000**	mA	0.000	22.000	**0.000**
20	AO1 out at AO1 src max	20.000	mA	0.000	22.000	20.000
21	**AO2 actual value**	4.000	**mA**	**0.000**	**22.000**	0.000
22	AO2 source	Motor current	NoUnit			Motor current
26	AO2 filter time	0.100	s	0.000	30.000	0.100
27	AO2 source min	0.0	NoUnit	-32768.0	32767.0	0.0
28	AO2 source max	**800.0**	NoUnit	-32768.0	32767.0	**100.0**
29	AO2 out at AO2 src min	**4.000**	mA	0.000	22.000	**0.000**
30	AO2 out at AO2 src max	20.000	mA	0.000	22.000	20.000
91	AO1 data storage	0.00	NoUnit	-327.68	327.67	0.00
92	AO2 data storage	0.00	NoUnit	-327.68	327.67	0.00

Figure 25- Standard AO Parameters



30. Limits						
1	**Limit word 1**	0b0000	**NoUnit**	**0b0000**	**0b1111...**	0b0000
2	**Torque limit status**	0b0000	**NoUnit**	**0b0000**	**0b1111...**	0b0000
11	Minimum speed	**850.00**	rpm	-30000.00	30000.00	**-1500.00**
12	Maximum speed	**3408.00**	rpm	-30000.00	30000.00	**1500.00**
13	Minimum frequency	**14.16**	Hz	-500.00	500.00	**-50.00**
14	Maximum frequency	**56.80**	Hz	-500.00	500.00	**50.00**
15	Maximum start current ena...	**Enable**	NoUnit			**Disable**
16	Maximum start current	**900.00**	A	0.00	30000.00	**1320.00**
17	Maximum current	**800.00**	A	0.00	30000.00	**1320.00**
18	Minimum torque sel	Minimum torque 1	NoUnit			Minimum torque 1
19	Minimum torque 1	-300.0	%	-1600.0	0.0	-300.0
20	Maximum torque 1	300.0	%	0.0	1600.0	300.0
21	Minimum torque 2 source	Minimum torque 2	NoUnit			Minimum torque 2
22	Maximum torque 2 source	Maximum torque 2	NoUnit			Maximum torque 2
23	Minimum torque 2	-300.0	%	-1600.0	0.0	-300.0
24	Maximum torque 2	300.0	%	0.0	1600.0	300.0
25	Maximum torque sel	Maximum torque 1	NoUnit			Maximum torque 1
26	Power motoring limit	300.00	%	0.00	600.00	300.00
27	Power generating limit	300.00	%	600.00	0.00	300.00

Figure 26- Limits

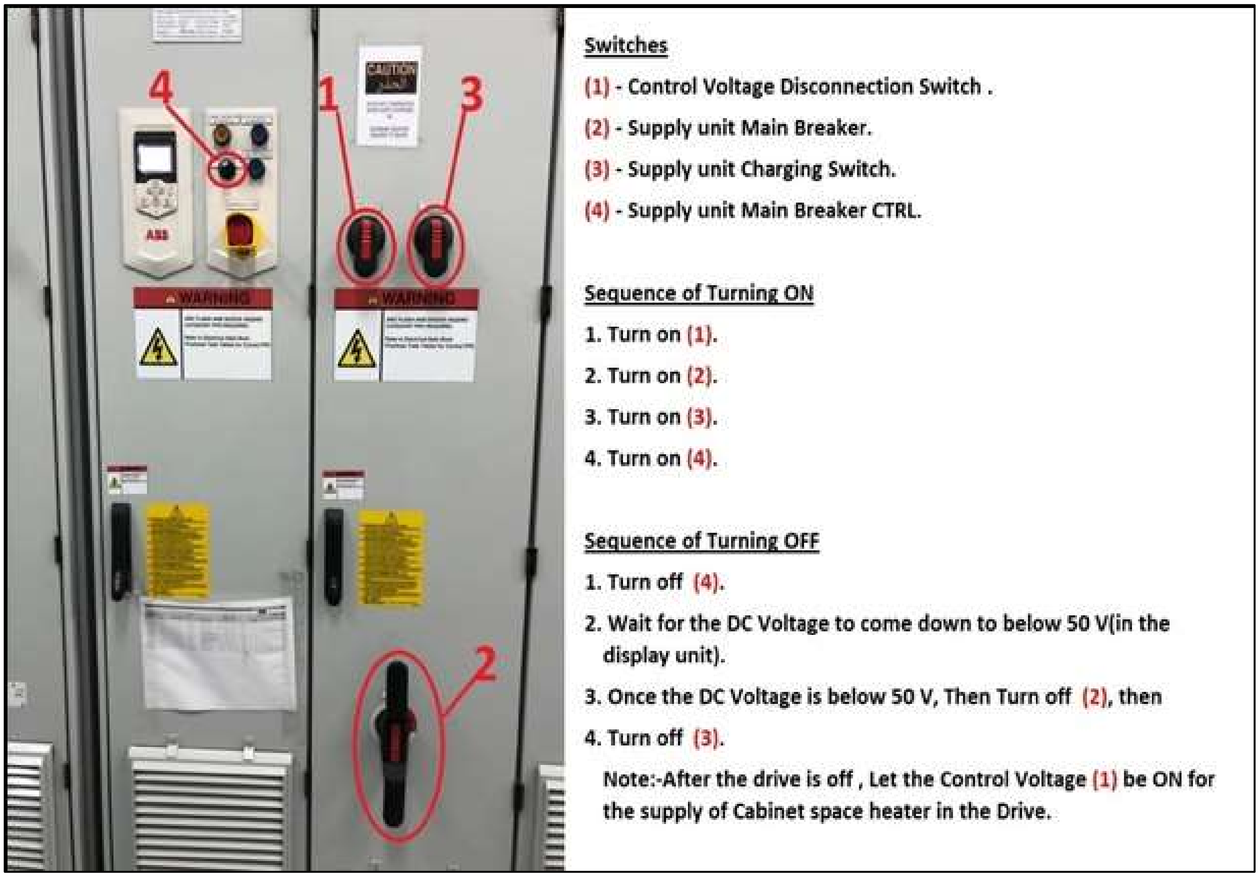


99. Motor data

3	Motor type	Asynchronous motor	NoUnit			Asynchronous…
4	Motor control mode	**Scalar**	NoUnit			**DTC**
6	Motor nominal current	**800.0**	A	0.0	6400.0	**0.0**
7	Motor nominal voltage	**460.0**	V	0.0	800.0	**0.0**
8	Motor nominal frequency	**57.00**	Hz	0.00	500.00	**0.00**
9	Motor nominal speed	**3408**	rpm	0	30000	**0**
10	Motor nominal power	**530.00**	kW	0.00	10000.00	**0.00**
11	Motor nominal cos φ	**0.87**	NoUnit	0.00	1.00	**0.00**
12	Motor nominal torque	0.000	Nm	0.000	400000…	0.000
13	ID run requested	None	NoUnit			None
14	**Last ID run performed**	Normal	**NoUnit**			None
15	**Motor polepairs calculated**	1	**NoUnit**	**0**	**1000**	0
16	Motor phase order	**U W V**	NoUnit			**U V W**

Figure 27- Motor Data

8. Turn ON the drive.
   Follow the below sequence for turning ON and OFF.



Switches

(1) - Control Voltage Disconnection Switch .

(2) - Supply unit Main Breaker.

(3) - Supply unit Charging Switch.

(4) - Supply unit Main Breaker CTRL.

Sequence of Turning ON

1. Turn on (1).
2. Turn on (2).
3. Turn on (3).
4. Turn on (4).

Sequence of Turning OFF

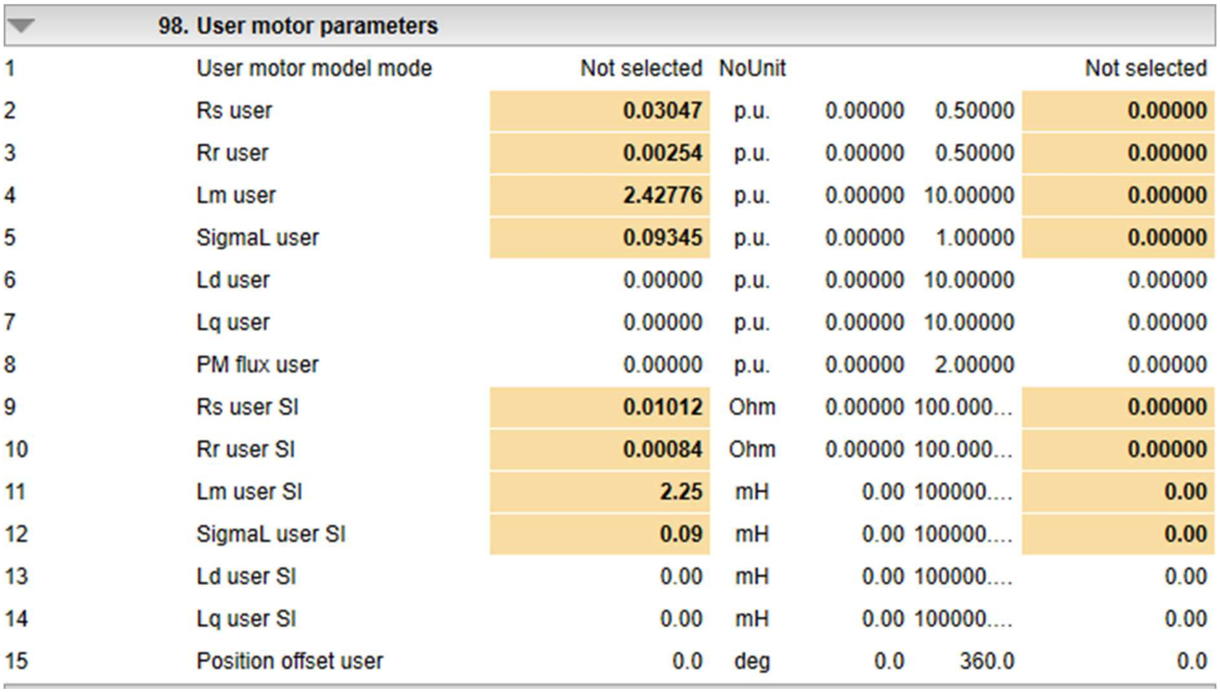
1. Turn off (4).
2. Wait for the DC Voltage to come down to below 50 V(in the display unit).
3. Once the DC Voltage is below 50 V, Then Turn off (2), then
4. Turn off (3).

Note:-After the drive is off , Let the Control Voltage (1) be ON for the supply of Cabinet space heater in the Drive.

Figure 28- Turn ON and Turn OFF of VFD

9. Perform the Identification run for the motor- Normal ID run for Uncoupled motors and if the motor cannot be uncoupled then go for standstill Id run.
   Use parameter 99.13 for Selecting the type of ID Run.
   The Last ID Run Performed can be viewed from the 99.14 parameter.’

   After the ID Run is completed the VFD gets the values for the ***98. User Motor Parameters*** values derived from Motor.



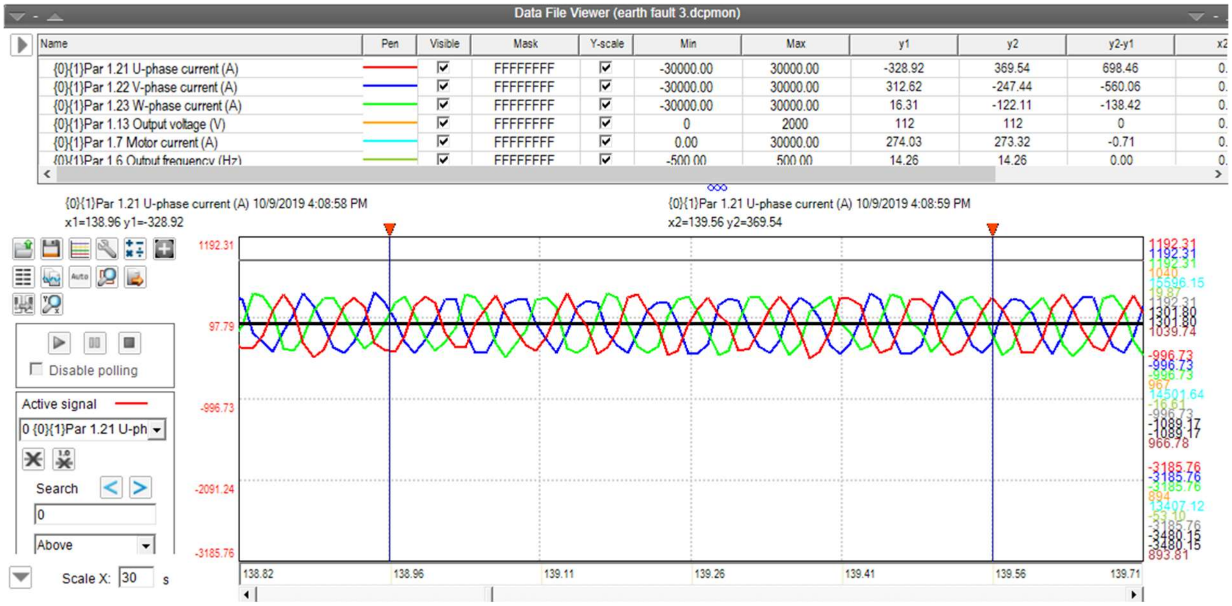
98. User motor parameters

1	User motor model mode	Not selected	NoUnit			Not selected
2	Rs user	0.03047	p.u.	0.00000	0.50000	0.00000
3	Rr user	0.00254	p.u.	0.00000	0.50000	0.00000
4	Lm user	2.42776	p.u.	0.00000	10.00000	0.00000
5	SigmaL user	0.09345	p.u.	0.00000	1.00000	0.00000
6	Ld user	0.00000	p.u.	0.00000	10.00000	0.00000
7	Lq user	0.00000	p.u.	0.00000	10.00000	0.00000
8	PM flux user	0.00000	p.u.	0.00000	2.00000	0.00000
9	Rs user SI	0.01012	Ohm	0.00000	100.000...	0.00000
10	Rr user SI	0.00084	Ohm	0.00000	100.000...	0.00000
11	Lm user SI	2.25	mH	0.00	100000....	0.00
12	SigmaL user SI	0.09	mH	0.00	100000....	0.00
13	Ld user SI	0.00	mH	0.00	100000....	0.00
14	Lq user SI	0.00	mH	0.00	100000....	0.00
15	Position offset user	0.0	deg	0.0	360.0	0.0

Figure 29- User Motor Parameters

10. Set speed/frequency control to minimum and energize the motor.

11. Slowly increase speed/frequency control until motor runs approximately 5% rated speed. Run for a short time and Record the Frequency, Output Voltage and Motor Current. Use the Online Monitor in the drive composer to capture the Trace data with all the required data.



Data File Viewer (earth fault 3.dcpmon)

Name	Pen	Visible	Mask	Y-scale	Min	Max	y1	y2	y2-y1	x2
{0}{1}Par 1.21 U-phase current (A)		☑	FFFFFFFF	☑	-30000.00	30000.00	-328.92	369.54	698.46	0.
{0}{1}Par 1.22 V-phase current (A)		☑	FFFFFFFF	☑	-30000.00	30000.00	312.62	-247.44	-560.06	0.
{0}{1}Par 1.23 W-phase current (A)		☑	FFFFFFFF	☑	-30000.00	30000.00	16.31	-122.11	-138.42	0.
{0}{1}Par 1.13 Output voltage (V)		☑	FFFFFFFF	☑	0	2000	112	112	0	0.
{0}{1}Par 1.7 Motor current (A)		☑	FFFFFFFF	☑	0.00	30000.00	274.03	273.32	-0.71	0.
{0}{1}Par 1.6 Output frequency (Hz)		☑	FFFFFFFF	☑	-500.00	500.00	14.26	14.26	0.00	0.

{0}{1}Par 1.21 U-phase current (A) 10/9/2019 4:08:58 PM
x1=138.96 y1=-328.92

{0}{1}Par 1.21 U-phase current (A) 10/9/2019 4:08:59 PM
x2=139.56 y2=369.54

Figure 30- Online Monitor

12. Verify motor accelerates smoothly. Check motor for noise, vibration, heating, if any abnormality occurs, check the settings of VFD.

13. Increase speed/frequency control until motor reaches 25% rated speed. Verify motor accelerates smoothly.
    Use the Parameter Group ***23. Speed Reference Ramp*** for varying the acceleration and Deceleration time.

14. Check motor for any noise, vibration, or heating. Run for a short time and Record the Frequency, Output Voltage and Motor Current. Continue using the Online Monitor in the drive composer to capture the Trace data.

16. Increase speed/frequency control until motor reaches 50% rated speed. Verify motor accelerates smoothly.
17. Check motor for any noise, vibration, or heating. Run for a short time and Record the Frequency, Output Voltage and Motor Current.

18. Increase speed/frequency control until motor reaches 75% rated speed. Verify motor accelerates smoothly.

19. Check motor for any noise, vibration, or heating. Run for a short time and Record the Frequency, Output Voltage and Motor Current.

20. Increase speed/frequency control until motor reaches 100% rated speed. Verify motor accelerates smoothly.

21. Check motor for any noise, vibration, or heating. Run for a short time and Record the Frequency, Output Voltage and Motor Current.

22. Record current and voltage output waves. Verify stability factor and harmonic content is within specified limits.

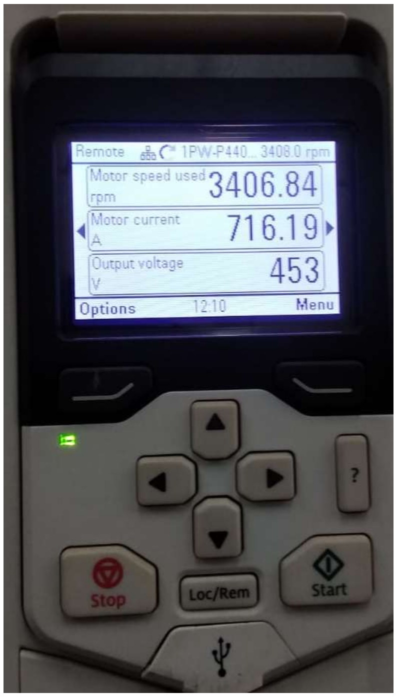
23. Reduce speed to minimum and verify motor decelerates smoothly without any noise or vibration.

24. Actuate the VFD Emergency stop function to stop the motor. Verify motor stops and the contactor supplying the motor opens.

25. Record settings of jumpers and potentiometers on VFD. Record speed settings for speed/frequency control, (attach it in a separate sheet)

26. Verify emergency stop control works and motor stops as required and control relays operate to properly disconnect power from the motor.

27. Run the motor from the DCS and ensure the current and speed scaling in the DCS and the actual values in the drive is matching.



Motor speed used rpm 3406.84

Motor current A 716.19

Output voltage V 453

Figure 31- VFD Display Unit